Without Miracles

10 Cultural Knowledge as the Evolution of Tradition, Technology, and Science

---

. . . the growth of our knowledge is the result of a process closely resembling what Darwin called 'natural selection'; that is, the natural selection of hypotheses . . .

--Karl Popper[1]

The analogy that relates the evolution of organisms to the evolution of scientific ideas can easily be pushed too far. But with respect to the issues of this closing section it is very nearly perfect. . . . Successive stages in that developmental process are marked by an increase in articulation and specialization. And the entire process may have occurred, as we now suppose biological evolution did, without benefit of a set goal, a permanent fixed scientific truth, of which each stage in the development of scientific knowledge is a better exemplar.

--Thomas Kuhn[2]

We have now considered in some detail two major ways in which biological structures, processes, and behaviors become adaptedly complex. We saw how through biological evolution those organisms that by blind chance possess variations in biological structure or perceptual control systems that provide survival and reproductive advantages will be more successful in passing on these structures and systems to their offspring. The cumulative selection of such advantageous modifications from one generation to the next (by the elimination of less successful organisms) can have dramatic effects on the evolution of a species and is also responsible for the origin of new species. This is phylogenetic selection among organisms.

We also concluded, however, that natural selection among organisms suffers from two notable drawbacks--it takes a considerable amount of time,[3] and it cannot be used by any *individual* organism to cope with an unpredictably changing environment or to learn from experience. An animal of a species that for millions of years depended on a particular food will have great difficulty surviving and reproducing if the food becomes unavailable, unless it can learn to find and use a substitute. Similarly, a mammal with a fixed repertoire of antibodies will be unlikely to survive if it encounters a new virulent strain of virus. But through ontogenetic variation and selection occurring within an animal's nervous and immune systems, it is possible for the animal to survive and reproduce even if its environment is quite different from that of its ancestors. The adaptation resulting from such lifespan evolution can occur quite rapidly and permit an organism to cope with a complex, changing environment, an important part of which is made of its fellow organisms with which it must compete for food, shelter, and mates. We noted in previous chapters, however, that such adaptation appears to be based on the same basic mechanisms of cumulative blind variation and selection that underlie the much slower and less responsive process of phylogenetic evolution.

But there is a third way, which we considered only briefly in chapter 9, in which adapted complexity can arise. Although strictly speaking it is a form of learning, it differs in some important respects from the type of learning we have already considered. Many organisms, particularly mammals and birds, are able to make good use of the experiences of their fellow creatures. Even the honeybee is able to profit from the experiences of hivemates who have discovered a new source of food. This learning from the learning of others is nowhere more developed than in humans where it is generally referred to as *culture*. Its role in both the remarkable proliferation of our species to all corners of the globe and in our continued survival demands that we consider its adaptedness and explain its origin and evolution.

Tradition

Of Rice and Religion

Rice is humankind's single most important food, providing nearly a third of all the calories we consume.[4] In tropical climates where three crops can be grown each year, as much as six tons of rice can be produced annually from one hectare (2.47 acres) of land. And this can be accomplished from the same land year after year for centuries without the addition of chemical fertilizers and pesticides.

To achieve and maintain these impressive yields, special, labor-intensive cultivation practices are required. First, seedlings are obtained by sowing rice into specially prepared seedbeds. After several weeks the seedlings are transplanted by hand to a flooded field or terrace where they are left to grow in 5 to 20 cm (2 to 8 inches) of water for several months. Two to three weeks before harvest, the paddy is drained. The rice stalks are cut and tied into bundles and allowed to dry before threshing separates the grain from the rest of the plant.

The most striking aspect of rice cultivation is the use of flooded fields or terraces, and this is the key to obtaining high, recurring yields. Flooding helps to keep essential nutrients in the soil that would otherwise be lost through leaching and exposure to the atmosphere. Under flooded cultivation other nutrients containing iron, aluminum, manganese, and calcium release phosphorus for use by the plants, instead of it remaining chemically bound to these minerals as it is when dry. More nitrogen is also available, since the oxidation of ammonia into nitrates is retarded, with the result that nitrates are produced at about the same rate as the plants can assimilate the nitrogen they contain (much of this nitrogen would otherwise be lost into the atmosphere). In addition, blue-green algae and a small water fern called azolla establish residence in the rice paddies. These plants have the rare ability to take in nitrogen directly from the atmosphere, which is then made available to the rice plant as the algae and azolla die and decompose. Finally, the ability of the plants to thrive in flooded fields despite the lack of oxygen at their waterlogged roots is due to their remarkably efficient system of air passages connecting their leaves above water to the roots below.

The Indonesian island of Bali is in many ways ideally suited to the cultivation of rice. Lying almost directly on the equator, temperatures vary little throughout the year from its 26deg. C (79deg. F) average. Rain can be expected to fall about 200 days each year, and humidity remains at a fairly constant 70% to 80%. The majority of the population inhabits the south side of the island on the slopes of mountains whose lakes and rivers provide a reliable and controllable supply of water for irrigation. It should therefore come as no surprise that rice and water are key elements in Balinese traditional life. Every morning the women lay out a few grains of cooked rice on squares made from banana leaves as offerings of thanks to Wisnu, the water god, and Dewi Sri, the goddess of rice and fertility.

Because wetland rice cultivation requires periodic flooding and draining, an extensive network of hillside terraces and irrigation systems exists on the mountainsides. But more than this is required to ensure efficient rice production. Although the climate is such that rice can be grown at any time of the year, the timing and movement of water down the terrace slopes must be carefully planned. Ideally, planting should be arranged so that the water can be moved down the slope, providing for periodic flooding and draining that corresponds to the growing cycle of each terrace. If decisions concerning planting and harvesting times were left up to each individual farmer, there would be the risk of taxing the water supply beyond its limits during one part of the year while seriously underusing the available water during other periods.

To coordinate this use of water, the Balinese have formed the *subak* or "irrigation society." This is a secular organization with taxing rights and a written constitution that provides one vote for each member; however, the ultimate authority of the subak is vested in Dewi Sri.[5] So the operation of the irrigation system makes best use of the available water, but the context in which the appropriate dams and sluice gates are opened and closed and the terraces are prepared for planting and harvesting is a religious one:

> The schedules of the various stages and water-openings are all set by the cycle of religious occasions that farmers are obliged to acknowledge with prayers and offerings. Included among these occasions are the days on which the ground should be broken (and not before), when the field should be flooded, when seed should be planted, and when the young seedlings should be transplanted. A large ceremony is held in the main subak temple when the rice is about to flower, and a full scale three-day festival takes place when the seed is set. There are lesser ceremonies, (pleading for good growth and for protection from pests, for instance), made at shrines in every field, and other large ceremonies are held as the crop ripens, when it is harvested, and when it is placed in the granary. . . . [There are between 9 and 16] specific religious occasions on which every subak member must make obeisance to the appropriate gods.[6]

As a result:

> In Bali, where maintaining high levels of wet-rice production in a relatively small area is made more complex by the rugged nature of the terrain, farmers have made a religion of their activities. Rice in Bali is not grown according to any production timetable that the modern agronomist might work out, but according to the stipulations of the temples and the rice goddess--and with very good effect. No Balinese rice farmer ever needs to consider the technical details of how rice should be grown to produce maximum crops from his land--precisely when to plough, when to flood, when to

> plant, when to drain and so forth. All he has to do is follow the calendar of *Dewi Sri*, the goddess of rice and fertility, and the crops are virtually guaranteed. Rice cultivation is the ultimate expression of the Balinese readiness to follow the edicts of some greater authority: the cult of the rice goddess not only demonstrates the integration of the secular and the spiritual worlds of Bali at the most fundamental level, it also provides an eloquent example of the functional significance of religion in human ecology.[7]

The fit between the cultural practices of the Balinese and the growing requirements of rice is well evident. But what is the explanation of this fit? If one were to ask a typical Balinese rice farmer, he would no doubt say that rice cultivation practices were provided by the rice goddess, since it is only by observing her calendar that continued good crops are ensured. Indeed, the fact that rice cultivation is so successful would appear to be quite convincing evidence that Dewi Sri is both knowledgeable and kind, and deserves respect, thanks, and praise, all of which she does in fact receive.

But quite a different picture emerges if we try to understand the farmers' knowledge of rice cultivation from a naturalistic perspective, that is, as somehow originating and developed without divine providence. This may first seem problematic, since it is quite unlikely that they would know anything about the extraordinary oxygen transport system that permits rice plants to thrive in flooded terraces, or the intricate biochemistry of wet-rice cultivation that ensures the plants an adequate supply of essential nutrients without depleting the resources of the land. So it might first appear that their farming knowledge must have been provided to them from some wiser source. But if we recall the remarkably fit products that biological evolution has been able to produce through the processes of cumulative blind variation and natural selection, we can appreciate that the rice-farming practices could have evolved similarly without the Balinese having explicit knowledge of the underlying reasons for their effectiveness. In much the same way birds have no formal understanding of physics, yet are able to use Bernoulli's principle quite successfully to fly. If over a long period of time biological evolution has produced palm trees, lobsters, panda bears, and humans, it should not seem unlikely that cultural evolution could result in an efficient system for the Balinese to produce their staple food.

Indeed, the view that culture originates and changes over time in a manner analogous to the cumulative trial and error of biological evolution has become increasingly popular among social scientists. As anthropologist John Reader explains:

> The farmers who founded and refined the wet-rice system and maintained its high levels of production for centuries knew nothing of nitrogen cycles and oxygen transportation in plants. They worked purely by trial and error. In the process, however, they acquired a sound appreciation of just what made the system work, and of how to keep it working.[8]

It cannot be doubted that the Balinese farmers are successful in cultivating rice, but is it actually the case that they "acquired a sound appreciation of just what made the system work"? For the traditional farmers it is observance of Dewi Sri's calendar together with participation in the many religious activities that are responsible for their success. Yet it can be easily shown that such religious observances are in no way essential to obtaining continued good rice harvests, since good harvests are obtained elsewhere in the world where the biological requirements of the rice plant are met and Dewi Sri and her calendar are totally unknown. So clearly a fit exists between Balinese farmers' agricultural practices and the requirements of the rice plant, although individual farmers may not know (and need not know) the underlying scientific reasons for it.

Regardless of a lack of technological or scientific understanding of rice cultivation, the society in which the rice farmer lives is structured in such a way to ensure continuation of the farming practices found over the centuries to be effective. By making it appear that these practices have divine origin and guidance, it is less likely that an individual farmer would challenge the system. So although daily rice offerings to the gods and frequent temple ceremonies in themselves have no direct causal link to the success of the crop, these traditional activities are well adapted in a larger sense since they ensure that traditional agricultural methods which have proved effective over the centuries will continue.

Does his lack of scientific understanding mean that the traditional Balinese farmer is in any way irrational or illogical in his adoption of the centuries-old methods of rice cultivation? Hardly, since for him rice cultivation and religious practices form one integrated system. It would be well nigh impossible for him to determine which particular aspects of his way of life are essential for obtaining continued good harvests and which are not. Indeed, such experiments (for example, refusing to participate in religious activities to see if this reduces rice yield) would possibly result in the radical farmer being ostracized from his community and make it impossible for him to obtain the water supply on which his crop depends. Instead, there are important advantages for individuals to adopt the agricultural and other traditional practices of the majority of their community.[9]

So since many aspects of traditional rice cultivation are not individually testable, we should not be surprised to find that some of them are not functional or are even maladapted to the requirements of rice production. The difficulty that an individual would encounter in attempting to analyze which aspects are actually well adapted and which are not, save for the fact that they may play important social functions, also argues for the rationality of accepting and observing the total cultural package.

Hidden Adapted Aspects of Tradition

On the other hand, many traditional customs, rituals, and taboos that may at first appear to lack any adapted qualities or may even seem maladapted, may on closer examination turn out to have interesting adapted characteristics. A classic example is the sacred cattle of India. With a population second only to that of China, India has difficulty feeding her people. Yet in the midst of this great need for food, millions of cattle are allowed to roam the countryside, trample gardens, and snarl traffic. According to traditional Hindu belief, the body of a cow is home to millions of deities, and the next reincarnation of the cow's soul will take human form; killing the cow sends its soul back to square one, and 86 more reincarnations are required to achieve cow status again. Thus Indians put up with the inconvenience posed by the cattle and would never consider butchering and eating one. This would appear to be an example of how traditional cultural beliefs and practices can be maladapted with respect to basic biological needs. "Orthodox Hindu opinion regards the killing of cattle with abhorrence, even though the refusal to kill the vast number of useless cattle which exist in India today is detrimental to the nation."[10]

If we take a more careful look, however, we can see that good reasons exist for the apparent folly of India's sacred cattle. In a classic paper published in 1966, American anthropologist Marvin Harris proposed that these cattle are on the whole beneficial to Indian society. They provide significant amounts of milk and meat (the latter eaten by Moslems, Christians, and lower-caste Hindus) as well as hides for India's leather industry, the world's largest. More than 300 million tons of manure are collected each year for use as cooking fuel in rural households, 90% of which have no other source of fuel. In addition, the cattle are regularly pressed into service as oxen, allowing millions of farmers simultaneously and quickly to plow their parcels of land to take full advantage of the sudden monsoon rains for their crops.

So we see that aspects of traditional culture that may at first appear to be at odds with the requirements of human life and reproduction may actually turn out to be in some respects quite functional, even if individuals are unaware of these adapted aspects and offer other reasons for their practices, such as concerns about reincarnation. This does not mean that the cattle situation in India could not be improved, only that if a striking although puzzling cultural practice has persisted over a long period of time, we may well expect to find some functional reasons for its existence if we look long and hard enough. But even if we do look long and hard, we may still fail to uncover functional explanations for many practices and beliefs found throughout the world in both so-called traditional and advanced societies. Can a theory of cultural evolution based on cumulative variation and selection of useful beliefs and practices account for this?

To attempt to make sense of the puzzle of apparently maladapted traditions, another problem will have to be considered. Many aspects of traditional culture may be beneficial to the society as a whole, but may be detrimental to the individuals who practice them. For example, in most societies people are expected to respect the property of others and to do their fair share of work. It is easy to appreciate how this is beneficial for the society as a whole, since if everyone simply stole what they needed no one would produce the required goods and services. Yet to the individual, it is advantageous, at least in a biological, evolutionary sense, to be selfish in doing the least amount of work possible, and to devote as much of one's energies as possible to staying healthy, mating, reproducing, and ensuring the survival and reproduction of one's own children. The cost involved to the individual in cooperating with society's conventions is most dramatically apparent in organized warfare, where men and women are expected to lay down their lives for the good of their community. Individual costs are involved in all instances of altruistic behavior, that is, when one individual pays the price of reduced reproductive success that benefits another's reproductive success. Thus we have the dilemma of explaining how individuals who are in reproductive (genetic) competition nonetheless quite often cooperate.

One way of understanding how such altruistic and cooperative practices could have arisen is to consider the genetic relatedness of the potential cooperators. If closely related individuals share a higher proportion of their genes than do less closely related ones, we can understand why a mother would risk her life for her children, since she is also likely protecting the genes that predispose her to do so. W. D. Hamilton made the first convincing arguments for *kin selection* as an explanation for altruism in two papers published in 1964. These papers provided an explanation for how cooperative behavior could evolve genetically (that is, by biological evolution) among genetically close relatives. And there is considerable evidence that for humans, cooperation is much more likely to occur, and dangerous violence is much less likely to occur, among close relatives.[11]

But we also find cooperative behavior among quite unrelated members of a species, and even involving different species. How can this be explained? One explanation is that it can be advantageous for an interacting group of organisms to cooperate instead of compete if the risk of noncooperation is high (for example, death in combat or lack of food) and if the individuals involved are likely to meet (and recognize each other) again. Robert Trivers coined the term reciprocal altruism to describe this type of cooperation,[12] and political scientist Robert Axelrod demonstrated using game theory and computer simulations how cooperation among unrelated individuals can evolve and remain stable.[13]

For such cooperation to evolve and persist, however, it must be possible to restrict the receipt of altruistic deeds to those individuals who will likely reciprocate. Otherwise, cheating in the form of accepting the benefits of others' altruistic deeds while providing nothing or little in return could become rampant and eventually undermine the cooperative nature of the community (those attempting to cooperate become "suckers" if recipients do not reciprocate). It is here that otherwise apparently useless or even maladapted traditions may be employed to indicate membership in the same reciprocally altruistic community. In this respect, "*easily perceivable* homogeneities in dialect, dress, rituals, and scarification would be particularly useful. Thus the Luo of Kenya knock out two front teeth of their men, while the adjacent Kipsigis enlarge a hole pierced in their ears to a two-inch diameter."[14] Although in itself a particular manner of dress or speech may seem to have no value as an adaptation, it may well take on importance as an easily perceivable sign of group membership and thereby facilitate in-group cooperation. In many American cities today, the manner in which a youth wears his baseball cap can mean life or death as he passes through areas in which rival gangs, distinguished in part by how they sport their caps, compete for control.

From this perspective, a number of otherwise puzzling aspects of traditional cultures become somewhat less puzzling. For example, some striking similarities occurred among the first city-state civilizations to emerge in Africa, China, the Middle East, India, and the Americas, including:

1. A division of labor and political centralization headed by a supreme, tyrannical ruler.

2. A belief in a supernatural cosmology that provided authority for the ruler.

3. A set of moralizing preachments that "preached the value of *duty to the political organization* and its customs . . . the duty of self-sacrificial military heroism in defense of the state . . . within-group honesty" and "preached against self-interested deviations from duty (covetousness, jealousy, etc.)."[15]

4. A belief in an afterlife of "rewarding and punishing heavens, hells, and reincarnation."[16]

In marked contrast to such uniformity, these civilizations had strikingly divergent beliefs concerning the *specifics* of the supernatural forces that appear to have played roles in the daily lives of their inhabitants. Different gods were praised and placated by various rituals and taboos. Such diversity argues for the independent origin of these beliefs and practices, although the function of each seems quite the same--to inhibit selfish behaviors that could undermine the cooperative structure of the community, and to encourage cooperative acts. To this end, all of these cosmologies (as do almost all existing religions) appear to have included a belief in an afterlife involving rewarding heavens and punishing hells. Wasteful royal funerals, in which "fully useful horses, soldiers, wives, weapons, jewels, and money were interred"[17] are a dramatic affirmation of such a belief. These funerals are a striking example of a practice that is downright wasteful in squandering hard-earned community resources, but that may be adapted at the social level as evidence of the reality of an afterlife. Thus they might motivate individuals to forego selfishness in this life to obtain the rewards of their socially adaptive cooperation in the next.

So it does appear possible to account for at least some of the apparently adapted and maladapted aspects of traditional cultural beliefs and practices using a model of cultural evolution that works at the level of the group. It also depends on cumulative variation, selection, and propagation not of genes, but rather of shared beliefs and practices. Because such aspects of tradition have proved themselves by the very fact that they have been around for a long time and that most people of a community observe them, it makes sense for individuals also to adopt them. But they are not confirmable as adaptive by the individual; indeed, even expressing doubt as to the truth of cherished traditional beliefs is often reason enough for banishment from the society or worse. In addition, traditions that distinguish members of one community from rival ones distinguish cooperative individuals from selfish ones. Therefore, we can expect some of tradition to appear useless and even maladapted to the biological demands of survival and reproduction, such as exorbitantly wasteful royal funerals.[18]

Technological Change

The second aspect of culture that we will consider is technology. Although today we tend to think of technology as involving powerful machines and sophisticated electronic equipment, in its more general sense it refers to any tools or methods that allow an easier or more efficient production of useful goods and services. A horse-drawn plow is a more effective and productive way of preparing soil for crops than is a shovel or hoe; nets for fishing have advantages over spears; and for covering long distances, air travel is superior in speed, safety, and comfort (if perhaps not in cuisine) to land and sea travel. Other species may use tools to a limited extent,[19] but none compares with us in terms of the variety and sophistication of our technological achievements. Each generation inherits crucial knowledge in the form of tools and procedures for providing food, clothing, shelter, health care, and protection from enemies. The acquisition of technology by individuals through either formal or informal education is essential to a society's continued survival and prosperity.

Not all would accept the claim that all, or at least many, cultural traditions are well adapted in any obvious material sense, although it was argued above that numerous traditional practices and beliefs are well adapted in at least some respects. The adapted nature of technology and its progress is harder to doubt. To increase production or provide better services at less cost and effort, technology must achieve an unlikely fit between its tools and techniques on one hand and the materials with which it is to work, the constraints of the physical world, and the limitations and preferences of human operators and consumers on the other. Nonetheless, human history is replete with examples of innovations that successfully (and increasingly) met the formidable odds imposed by these demands. Stone tools, the wheel, the horse collar, the plow, iron, paper, the spinning wheel, the clock, the cotton gin, the printing press, steam and internal combustion engines, barbed wire, the electric motor, the vacuum tube, the transistor, and the computer microchip are just a few examples of items developed in China, Europe, and the Americas. Because every successful innovation provides a demonstrably better way of producing some good or providing some service, each represents yet another puzzle of fit.

The similarity between the biological evolution of organisms and the technological evolution of tools, machines, and instruments has not escaped the attention of those attempting to describe, explain, and predict technological progress. As early as 1863 English writer and critic Samuel Butler explored the theory that machines develop in a way that resembles the evolution of living organisms. Indeed, Butler was so impressed by the rapid evolution of machines during the Industrial Revolution that he predicted that they would eventually constitute a new class of living things that would surpass the sophistication of humans and relegate us to second-class status.[20]

Although Butler's account of the evolution of machines was more satire than science, there have been serious attempts to understand the development of technology as an evolutionary process. Three recent books provide good examples.

The Evolution of Artifacts

In *The Evolution of Technology*,[21] George Basalla continues Butler's consideration of made things (artifacts) as analogous to living organisms. First, he argues for the continuity of technological innovation: "Any new thing that appears in the made world is based on some object already in existence."[22] New inventions do not emerge magically from the minds of great inventors, but rather are modifications of previously existing artifacts. In 1793 Eli Whitney's cotton gin that removed seeds from short-stapled cotton was based on the Indian *charka*, which had been in use for thousands of years to remove seeds from long-stapled cotton. Joseph Henry's electric motor of 1831 copied many of the mechanisms employed in the steam engine. The development of the first transistor at Bell Laboratories in 1947 by Bardeen, Brattain, and Shockley owed much to the work of German physicist Ferdinand Braun who, in the 1870s, found that certain crystals conduct electricity in only one direction.

Second, Basalla points out the diversity of artifacts that are available to any society, recognizing that certain cultures display more diversity than others. The source of this diversity can be found in psychological, socioeconomic, and cultural factors including the fertility of human imagination, our proclivity to play and fantasize, and the imperfect copying that invariably results when a person attempts to make an artifact based on an already existing one. An example of this diversity is the more than 1000 smokestack designs that were patented in the United States during the nineteenth century in the unsuccessful attempt to prevent the escape of embers and sparks from wood-burning locomotives.[23]

In the same way that organisms produce more offspring than can survive, there are often more variations of a given tool or machine than can survive and be taken up by the next generation of users. Thus selection becomes the third essential element of Basalla's view of technological evolution.

> From the vast pool of human-designed variant artifacts, a few are selected to become part of the material life of society. In nature it is the ability of the species to survive that counts--the fact that the organism, and especially its kind, can thrive and reproduce in the world in which it finds itself. The artifact may also be said to survive and pass on its form to subsequent generations of made things. This process requires the intervention of human intermediaries who select the artifact for replication in workshop or factory.[24]

Technology as Knowledge

Joel Mokyr's *The Lever of Riches*[25] is an engaging historical account of technological advances in Europe and China. Mokyr sees technological innovation as the major motor of economic growth, a way of providing occasional "free lunches" and many "cheap lunches" in that the cost of a successful innovation is paid for many times over by the increase in productivity it makes possible. Like Basalla, Mokyr suggests an evolutionary, selectionist account of technological development, but instead of giving a primary role to the artifacts themselves, he emphasizes the growth of human knowledge as the basic unit and gives analogues in technological evolution for the genotype and phenotype of living species.

> The approach I adopt here is that techniques--in the narrow sense of the word, namely, the knowledge of how to produce a good or service in a specific way--are analogues of species, and that changes in them have an evolutionary character. The idea or conceptualization of how to produce a commodity may be thought of as the genotype, whereas the actual technique utilized by the firm in producing the commodity may be thought of as the phenotype of the member of a species. The phenotype of every organism is determined in part by its genotype, but environment plays a role as well. Similarly, the idea constrains the forms a technique can take, but adaptability and adjustment to circumstances help determine its exact shape. Invention, the emergence of a new technique, is thus equivalent to speciation, the emergence of a new species.[26]

Mokyr's approach is therefore more psychological and epistemological than Basalla's in insisting that technology "is not something that somehow `exists' outside of people's brains."[27] His perspective is also more concerned with economics in the priority he gives to "lowest quality-adjusted cost" as the major criterion for selecting among the competing technologies present in a society at any one time.

Technology as Vicarious Variation and Selection

Certainly one of the most marvelous of all technological achievements is the creation of machines that fly. In *What Engineers Know and How They Know It*, Walter Vincenti presents five detailed case histories of important innovations that paved the way for the success of the modern airplane.[28] In his last chapter, he uses these cases to garner evidence for a "variation-selection model for the growth of engineering knowledge." Drawing heavily from Campbell's work, he breaks away from the limits imposed by the rather strict biological analogy employed by Basalla and Mokyr and makes a compelling case for a more general selectionist account of technological development.

Vincenti emphasizes the advantages of vicarious over direct trials in arriving at successful designs for technological innovations. Direct trials refer to the actual building of a new device and trying it out for its intended purpose to determine its degree of success or failure. Such direct trials of overt variations characterize the attempts of the French between 1901 and 1908 to develop flying machines.[29] During this time the French built a wide variety of aircraft and tested one after the other, usually with disastrous results. Not basing their trials on any systematic attempt to discover the basic principles of flight, there was little in the failure of one design to inform the design of the next, and the continuous building (and subsequent crashing) of working prototypes consumed considerable time and resources.

In contrast, vicarious trials for designing new technologies permit both expansion of the variations to be considered as well as a much more efficient (in terms of time and energy) selection process. Vicarious trials can be either experimental or analytical. Experimental ones consist of "the substitution of partial experiments or complete simulation tests for proof test or everyday use."[30] An example is the use of wind tunnel testing in aeronautical engineering. The Wright brothers' extensive use of such tests gave them an important advantage in the race to build the first airplane, since during the time it would take their French competitors to build and launch yet another complete prototype, the Americans built, tested, eliminated, and designed many different scale models and therefore made more rapid progress in their search for a successful design.

Analytical vicarious trials are even further removed from direct trials in that they use more abstract tools to test the worthiness of a particular design variation. They can be considered a kind of "test run on paper,"[31] although since computers are increasingly used for such tests today, they are more often test runs on computer silicon. "As each hypothetical arrangement of parts is sketched either literally or figuratively on the calculation pad or computer screen, the candidate structure must be checked by analysis. The analysis consists of series of questions about the behavior of the parts *under the imagined conditions of use after construction*."[32] It is through such tests that scientific knowledge can be exploited in technological development.[33] The Wright brothers profited from an analytical approach due to their knowledge of the principles of fixed-wing flight developed in the early 1800s by Sir George Cayley. This knowledge permitted the brothers to analyze the problem of flight into three subproblems consisting of lift, thrust, and control. By attacking each of these problems separately using vicarious experiments, they made rapid progress in designing the first machine capable of sustained manned flight.[34]

In emphasizing the importance of vicarious variation and selection, Vincenti in effect has described a technology of technology, this meta-technology providing better and better tools for developing new technology and making possible the ever-quickening pace of development. As these tools develop, they permit more efficient and reliable vicarious testing of variations on existing ideas. This also permits a broader scope of variations that can be tested efficiently. In effect the range of variations can actually be increased without detriment and possibly with great advantage, since the new vicarious means of variation and selection are so rapid and efficient in weeding out the unfit variations. As Vincenti has remarked, "engineers have freedom to be increasingly blind in their trial variations as their means of vicarious selection become more reliable. One sees engineers today, for example, using computer models to explore a much wider field of possibilities than they were able to select from just a decade ago."[35]

The Development of Science

The final aspect of culture to be considered here is scientific knowledge. Technological knowledge can be put to *practical use* to solve problems concerning the production of goods and services. Scientific knowledge provides *explanations* for observed phenomena in terms of underlying mechanisms, thus providing a basis for predictions and perhaps ultimately controlling the phenomena under study. Technology may help to advance science, especially in providing new tools for exploration such as orbiting telescopes, electron microscopes, and powerful computers. And science can aid technology, as particle physics made possible nuclear weapons and nuclear power plants. But the two can be seen as distinct. The Australian bushman's ability to produce boomerangs is technological knowledge that does not depend on scientific knowledge of physics and aerodynamics. And the greatest scientific discovery of the nineteenth century owed little to technology, other than that involved in building and navigating the *Beagle*, the ship that allowed Darwin to experience firsthand the world's remarkable diversity of life, in particular the subtle differences in species found scattered among the Galápagos Islands.[36]

Science provides what many consider to be the most striking and undeniable instances of fit of one system--human knowledge--to another--the universe in which we live. It is for this reason that countless philosophers and scientists have attempted to understand how this remarkably complex and fit aspect of our culture is achieved.

Bacons Systematic Method of Induction

Sir Francis Bacon (1561-1626) lived in England during the dawn of the modern Western scientific and technological era. He was greatly impressed by the astronomical discoveries of Copernicus and Galileo, which provided a radically new view of the universe, and the technological achievements represented by such inventions as gunpowder and the printing press. But Bacon had little patience for the speculative philosophers of his time who, he believed, had made little if any progress in understanding nature since the time of the Greeks. He felt strongly that it was only through a carefully implemented scientific methodology that we would be able to understand the world around us and regain the mastery over nature that was lost at the time of the fall of Adam and Eve.

But Bacon believed that more than just mastery over nature had been lost. The human mind was also corrupted by false images or idols, which caused it to perceive the world in unreliable and subjective ways. These idols included the tendency to seek out and see only confirmations of already held beliefs, and the proclivity to notice the more striking aspects of the world while failing to see the subtler ones. Bacon held that these impediments to objective and accurate observation had to be swept away, leaving the mind as a blank slate so that the world could accurately transmit and impress its true nature on the human mind.

To this end he offered a systematic method of induction based on careful observation, comparison, and experimentation. For instance, to understand the true nature of heat, one has to find many instances of heat and determine by observation what they have in common. But positive instances alone do not suffice. One must also find negative instances, in particular, instances that are very similar to the positive ones but that lack the quality of interest. It is only by listing and comparing instances in which the phenomenon of interest is present with those in which it is absent that the true nature of the phenomenon can be ascertained.[37] By mechanically following this method, Bacon believed that one would eventually arrive at valid inductions concerning the makeup and behavior of the natural world that could then be applied deductively to predict and control natural phenomena. Such a view of scientific knowledge is referred to today as empirical positivism, since it is based on the belief that careful empirical observation can provide us with certain (or positive), justified knowledge of the universe's content and laws.

The Problem of Induction

Bacon's writings on science and its method had a great impact in England and on the European continent. Both Newton and Darwin acknowledged their debt to Bacon, and shortly after his death various scientific societies, such as the Royal Society in England and similar institutions on the continent, were established to undertake the type of systematic, scientific research that Bacon had advocated. Indeed, the remarkable success of Newton in discovering the laws of nature that govern the movements of both terrestrial and celestial bodies hinted that it was only a matter of time before all of nature's secrets would eventually be uncovered using the empirical, inductive method based on unbiased observation and objective comparison.

But this was not to happen in the manner envisaged by Bacon and the new breed of empirical scientist whom he influenced. A century after his death, David Hume (see chapter 6) pulled the epistemological rug out from under all attempts to arrive at a foolproof method of induction by which general laws and theories could be discovered and justified by unprejudiced observation of the natural world. In fact, it would appear that Bacon was at least partially aware of the impending problem, as indicated by the importance he placed on negative instances, as he shows in this account of the power of prayer:

> And therefore it was a good answer that was made by one who when they showed him hanging in a temple a picture of those who had paid their vows as having escaped shipwreck, and would have him say whether he did not now acknowledge the power of the gods,--"Aye," asked he again, "but where are they painted that were drowned after their vows?" And such is the way of all superstition, whether in astrology, dreams, omens, divine judgements, or the like.[38]

Bacon's concern with negative instances anticipates Popper's similar emphasis on the essential role of refutation in science (to be discussed next). But it apparently did not occur to Bacon to wonder, as it did later to Hume, that if a negative instance (for example, experiencing silent lightning) can lead one to reject a belief (that all lightning produces thunder) previously supported by countless observations, how could one be sure that for any general belief supported by observation that a negative instance does not exist somewhere? Inasmuch as it is not possible to prove that negative instances do not exist somewhere, it is not possible to be absolutely certain of the truth of any general belief, scientific or otherwise, no matter how well the belief has been supported by past empirical observations.

Despite this serious logical and methodological difficulty, however, science does appear to make progress in ways in which other belief systems, such as religion, astrology, and palmistry, do not. If science is indeed able to attain progressively better fit to the world it describes, we are left with the puzzle of how this fit is achieved, since it is evident that empirically based induction of the type advocated by Bacon and found wanting by Hume is simply not up to the task of providing infallibly true knowledge of the world.

Popper and Falsification

Science continued to make important breakthroughs at an accelerating pace from the seventeenth through the twentieth centuries. It could be argued, however, that no comparable breakthroughs occurred in understanding how science was able to continue to make progress, that is, achieve better and better fit with the objects and phenomena it described, until Sir Karl Popper (1902-1994) confronted the problem. Popper grew up in Vienna during a time of great intellectual and scientific activity in Europe in general and in the Austrian capital in particular. As a student of the philosophy of science, he was fascinated by the ability of science to achieve better and better fits to the world it described, and consequently he set his mind to determining what it was that set science apart in this respect from nonscientific domains. What was it that allowed Newton and Einstein to propose theories that were convincingly better than those provided by their predecessors, whereas the political and economic theory of communism offered by Marx and the psychoanalytic theory developed by Freud were not demonstrably better than competing theories? Popper proposed a simple yet bold solution to this problem of the "demarcation" of science from nonscience and in so doing offered a solution to the vexing problem of induction raised by Hume.

According to Popper, what sets science apart from nonscientific beliefs and theories is that scientific theories are *falsifiable*. For instance, one of Newton's laws of physics is that force is equal to mass times acceleration. This theory can in principle be falsified by experimentation, since it makes specific testable predictions. If the theory is correct, it should take the same force to impart a certain acceleration to an object as it takes to impart twice this acceleration to an object which has half the mass. If this is found not to be the case, and no methodological errors have been made, the theory must be rejected and a better one formulated and tested in its place. This contrasts with Freud's psychoanalytic theory, which is formulated in such a way as to make it immune from falsification. If psychoanalytic theory says that all males are jealous of their father and covet their mother but a certain male denies having these feelings, a confirmed Freudian would argue that the male was repressing his true feelings of paternal jealousy and maternal desire. Similarly, fields such as astrology and palmistry are not scientific, since if a prediction does not prove accurate, reasons can always be found after the fact why things did not turn out as foretold.

Popper's discovery of the importance of falsification also had a side benefit in that it solved the problem of induction. As already noted, a scientific theory that proposes a general, universal law of nature can never be rationally justified, since by virtue of its universality it must go far beyond the limited observations of mortal scientists. So no matter how many times it is observed that event A is followed by event B (for example, heating water to 100deg. C causes it to boil), it cannot be proved logically that all A are followed by B. But whereas apparently confirming cases cannot justify a scientific theory, disconfirming cases do allow us to refute it. Finding a clear instance of A that is not followed by B (for example, finding that in Death Valley water at 100deg. C does not boil) means that our theory must be revised or abandoned. Then a new theory must be proposed that accounts for all that the old theory accounted for as the well as new findings that it could not handle. According to Popper, the fit of science is not due to observation and induction of true, justified (or justifiable) theories, that is, the accurate, instructive transmission of knowledge from the environment to the scientist. Rather, science progresses through the creation of conjectures (guesses) and the subsequent weeding out of inadequate hypotheses, leaving those that are better than the ones eliminated only because they have not yet been eliminated themselves.[39]

It did not escape Popper's attention that his view of the process of scientific achievement had much in common with Darwin's selectionist theory of biological evolution:

> The growth of our knowledge is the result of a process closely resembling what Darwin called "natural selection"; that is, *the natural selection of hypotheses*: our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) fitness by surviving so far in their struggle for existence; a competitive struggle which eliminates those hypotheses which are unfit. [40]

Popper's view of scientific progress as a cumulative selection process throws interesting new light on science and its achievements. First, in the same way that biological evolution depends on the existence of blind variation in the structure and behavior of organisms, science depends on similar blind variation in hypotheses that are proposed. This does not mean that the hypotheses are not constrained by the knowledge already achieved. No respectable scientist is going to propose that the core of the earth is made up of strawberry jam or the moon's surface is Swiss cheese. And no whale is likely to give birth to a horse. In both biological evolution and science, such constraints reflect the past accumulation of knowledge by prior blind variation and selection and are essential in narrowing down the types of future variations that appear. But the constraints alone cannot account for the emergence of new and better fits of organism to the environment, and scientific theory to the universe.

Second, an evolutionary perspective accounts for the tentative nature of scientific theories. Each now-extinct species, which together make up a much larger number than those species still extant, had before its extinction been successful in surviving for quite some time, in some cases hundreds of millions of years. But in none of these cases was this long period of survival (which is clear evidence of fit to the environment) able to guarantee the future success of the species. Similarly, the long-term, popular acceptance of a scientific theory in no way guarantees that it will not become extinct as better theories evolve to compete with it and eventually replace it. The phlogiston theory of fire, the caloric theory of heat, the ether theory of outer space, Newton's theory of mechanics, and Lamarck's theory of evolution have all been eliminated in the struggle for survival described by Popper, despite the fact that each was the best and dominant theory of its day. So in addition to explaining how science can achieve progressively better fit to the universe, the selectionist view as proposed by Popper explains why we can never justify any particular theory as absolutely and infallibly true. In the same way that previously successful species become extinct, scientific theories are eliminated and replaced by better ones.

Finally, a selectionist view emphasizes the creative role of the scientist. Popper contended that the scientist's mind is not an epistemological bucket that is filled with knowledge from the environment through the eyes, ears, and other sensory organs. This is not unlike a Lamarckian view of evolution in which the environment somehow instructs the reproducing organism to create new adapted forms. Instead, the scientist actively constructs knowledge in the form of unjustified theoretical conjectures, which are then tested and compared to competing conjectures. In this way, the scientist's experience of the world does not provide the theories to be tested. Rather, observation is used to weed out the unsatisfactory ones already constructed. As it is not possible to predict the course of biological evolution, it is similarly impossible to predict the future course of science. And because technological and social changes are strongly influenced by scientific developments, it is similarly impossible to predict the future course of history.[41]

As falsification is the key ingredient to Popper's philosophy of science, it should come as no surprise that Popper valued serious attempts to falsify all proposed scientific hypotheses because it is only in this way that the better theories can be selected and the poorer ones eliminated. For this reason, Popper believed it is important that scientific theories be given an "objective" existence in the form of spoken or (even better) written words and other symbols that can be disseminated widely to other scientists for scrutiny, for example, in the form of conference presentations and publications.[42] The critical worldwide attention any important new scientific theory now receives makes it increasingly difficult for inadequate theories to survive for very long, as shown by the animated flurry of research and refutation that followed the announcement of cold nuclear fusion by two University of Utah physicists in 1989. Indeed, it will be argued later that the increasingly strong global selection pressure put on theories is an important factor in science's rapid progress, and that considerably less global selection pressure has been put on tradition and technology.

It should not be surprising that a philosophy of science as radically different as Popper's has attracted considerable criticism.[43] But whereas some philosophers continue their search for a completely reliable scientific method based on the foolproof induction of general scientific laws from observation and experiment, modern mainstream philosophy of science has joined Popper at least insofar as rejecting an empiricist, transmission perspective based on justified induction, and taking instead a much more cautious, probing, fallible, tentative, and often evolutionary view.[44]

Tradition, Technology, and Science as Forms of Adaptive Evolution

Genes, Memes, Replicators, and Interactors

We have now seen that current attempts to account for the adapted complexity of culture--whether it be in the form of traditional beliefs and behaviors, technology, or science--have increasingly turned away from providential and instructionist theories, toward evolutionary, selectionist ones. But what are the actual mechanisms by which culture evolves? Unfortunately, what we know of the details of cultural evolution does not begin to compare with what we know of the details of biological evolution.

Darwin was in much the same position when he proposed the theory of natural selection. He could see the competition among organisms and the merciless hammer of nature eliminating the less fit organisms unable to survive and reproduce in sufficient numbers. However, he had no adequate theory of inheritance, and knew nothing of genes, their molecular structure, and how their mutation and recombination provide the blind, probing variation on which selection operates. We know now that genes play the role of replicators, since they make copies of themselves that are handed down from parent to offspring, and that interact with the offspring's environment in determining the form and behavior of the individual. But it is the fit of the organism's form and behavior, with respect to its interaction with its inanimate and animate environment, that determines whether any particular organism will be successful in surviving to maturity and reproducing. In this sense, organisms or groups of organisms can be considered to be the *interactors* on the stage of evolution, and it is at the level of interactors that selection takes place.

The distinction between replicator (genotype) and interactor (phenotype) is important as it helps to clarify certain long-standing problems and controversies concerning the units of selection in biological evolution.[45] Similarly, the distinction may be of use in understanding cultural evolution as well. But then we must ask, what are the replicators in cultural evolution? For cultural evolution we require an entity that is analogous to the gene in biological evolution. This replicating entity is now referred to as the *meme*.[46]

The meme is a unit of cultural replication. As originally introduced by Dawkins:

> Examples of memes are tunes, ideas, catch-phrases, clothes fashions, ways of making pots or building arches. Just as genes propagate themselves in the gene pool by leaping from body to body via sperms or eggs, so memes propagate themselves in the meme pool by leaping from brain to

> brain via a process which, in the broad sense, can be called imitation. If a scientist hears, or reads about, a good idea, he passes it on to his colleagues and students. He mentions it in his articles and his lectures. If the idea catches on, it can be said to propagate itself, spreading from brain to brain. [47]

Admittedly, the meme is not quite the tidy conceptual entity that the gene is. Whereas genes consist of sequences of four nucleotide bases comfortably nestled in spiraling molecules of DNA, memes can take on many different forms, from articles of clothing and spoken words to written pages and computer programs. These various types of memes can all replicate, and at a rate that leaves biological evolution far behind. A new word or phrase used by a character in a popular movie can result in millions of copies worldwide within a few weeks. The idea behind a new technology can also spread quickly in a short amount of time, which is why patents were invented to protect the rights of inventors. And a new and better scientific theory published in a prestigious scientific journal will quickly replicate in the minds of scientists and students throughout the world.

But memes, like genes, do not determine on their own whether and how quickly they will replicate. For this they require interactors who, in cultural evolution, are human agents who in interaction with their environments determine which memes are to be selected and, consequently, replicated. Any achieved cultural fit must be due to the ability of the interactor-environment interface to eliminate less-fit memes. If Einstein's theory of relativity replaced Newton's theory of mechanics because it is an improvement over Newton's, something in the interaction of scientists with their environment must have led to the elimination of the Newton meme and the propagation of the Einstein meme. Indeed, if culture is to achieve progressively better fit with its environment, this environment must somehow participate in selecting the interactors resulting in the subsequent differential replication of the interactors' memes.

Tradition, Technology, and Science: Similarities and Differences

Participation of the environment in the selection of memes would appear to be necessary for all forms of cultural fit, but there are important differences in how this participation takes place. Adapted traditional beliefs and behaviors, as seen in rice planting in Bali, take a very long time to develop and change. That is because the selection process does not depend on individuals as interactors, but rather on a much larger social group. Indeed, as already mentioned, individuals often do not even have the option of intentionally changing traditional beliefs and practices, since to do so might result in banishment from the group or perhaps even death. So the selection process for tradition operates very slowly, at least when compared with other forms of cultural evolution.

The situation is quite different for technological development. In experimenting with new techniques for producing goods and services, individual artisans and inventors are able to test the worth of various memes and select the ones that are best suited to the task at hand. So technological change based on individuals as interactors can occur much more quickly than traditional change based on societies as interactors. To the extent that technology evolves means of vicarious variation and selection (as in the Wright brothers' use of wind tunnels and scale models to test airplane designs), adaptive technological change can occur at even faster rates.

The same is true for science. But scientific development differs from technological development in another important way. In technological innovation, the individuals who come up with promising innovations are most often the same people who test them. It was the Wright brothers and they alone who tested all the variations in wings and propellers they imagined might be successful. But in science today, the individuals involved in testing new theories are not usually restricted to the originators of theories. Important new scientific theories are typically published in widely read scientific journals, and such publication requires stringent peer review by fellow scientists. The more abstract nature of science and the easily communicated mathematical and natural language in which its memes are expressed makes it possible for scientific memes to proliferate quickly to others worldwide. This puts enormous selection pressure on the memes since large numbers of scientists will be eager to falsify any new theory that receives widespread attention, and many of them may well propose theories of their own. Of course, exciting new technological innovations are also eventually tried and tested by individuals not involved in their creation, and much scientific testing requires new technology as well. But we can nonetheless expect a new scientific theory such as $E = MC^3$ published in a prestigious physics journal to undergo more rapid and more widespread attempts at falsification than a new design for automobile tires.

Although some important differences exist in the evolution of tradition, technology, and science with respect to the selection process, in another respect they are very much alike in that the new memes that are tested arise by the blind variation of previously existing memes. When humans first attempted to understand the invisible causes of visible events such as lightning or disease, they conjured up myriad gods, spirits, and other mysterious entities and forces, many of which remain with us to this day. When a physicist or biologist attempts to understand the same phenomena, entities and forces no less mysterious appear in the form of electromagnetic fields, unimaginably small viruses, and still tinier subatomic particles. At this point there is no fundamental difference between superstition and science. The difference lies in the selection procedure and in the fact that scientific memes must be in principle falsifiable in such a way that the phenomena to which they refer participate in the selection. We cannot falsify the belief that evil spirits cause a particular illness, since the spirits are by definition undetectable and make their presence known only through the disease. We can, however, reject the hypothesis that a particular virus or bacterium causes a certain disease. But although science can and does make significant progress in the cumulative introduction and winnowing of new memes, it can never lead us to the positive, infallible knowledge scientists continually seek.

The Myth of Cultural Transmission

Although attempts to understand adaptive cultural change as a selection process analogous in important ways to adaptive biological evolution have become increasingly common, it should not be overlooked that this approach has many critics. A discussion of the criticisms will be saved for chapter 15, but one of the most cited differences between biological and cultural evolution will be addressed here--the claim that biological evolution is Darwinian and cultural evolution is Lamarckian.

By this it is meant that biological evolution is a process of blind variation of genes and subsequent selection of organisms containing these genes by the environment, whereas cultural evolution proceeds by the transmission of acquired characteristics. On the surface, this may indeed appear to be the case. We currently know of no way by which any adaptive changes to an organism's form or behavior acquired during its lifetime can be encoded in its genes and consequently passed on to its offspring. As Weismann claimed (and molecular biology has not yet been able to refute), changes in genes can result in changes in the structure and behavior of organisms, but acquired changes in an organism's structure and behavior resulting from use, disuse, or learning cannot be encoded in the genes. In other words, information is not transmitted from environment to genome. The role of the environment is solely one of selection, not instruction or transmission.

In contrast, it is claimed that cultural evolution is Lamarckian in the sense that the cultural knowledge that one person acquires during a life-time can be transmitted to another. If I discover a better way of growing potatoes, I can show you how it is done and then you can use the new method as well. My newly acquired potato-growing practices can be inherited culturally by my children, as well as by other individuals with whom I come in contact or who learn about my new, adapted memes through books, word of mouth, or other indirect means, and thus this process may initially seem Lamarckian in nature. In fact, many who have made the most valuable contributions in developing evolutionary models of cultural change speak of cultural transmission in this sense, [48] and Dawkins was quoted earlier describing how "memes propagate themselves . . . by leaping from brain to brain."

But to understand how cultural change might be Lamarckian, we must consider carefully just what is meant by transmission and what is transmitted. It should first be pointed out that a selectionist theory of adapted complexity does not rule out all forms of transmission. Indeed, one can certainly consider the replication of genes that is required for reproduction to be genetic transmission. This can be seen most clearly in asexual organisms whose offspring are almost always genetically identical to the parent. Thus, the parent's genetic code is transmitted to the offspring.[49] But what is essential to keep in mind is that transmission is not responsible for the fit of a genome to its environment. This fit comes about through Darwinian selection, not Lamarckian transmission or instruction. If we are interested in explaining puzzles of fit, we are primarily interested in how the fit comes about, and only secondarily interested in how it is replicated and propagated once it is achieved. So genetic transmission plays an indispensable role in biological evolution, but its role is a secondary one of preserving and propagating the fit *that has already been achieved through selection*.

Having made the distinction between the achievement of fit and the propagation or replication of fit, we can better assess the role that Lamarckian instructive transmission might play in cultural evolution. With respect to achieving the initial fit of cultural knowledge to environment, modern postpositivist philosophy such as Popper's, as well as much current psychological theory, convincingly maintains that this fit cannot be the result of instruction from the environment to the individual. If there is a fit of knowledge to the environment, the role of the environment is one of selecting from among the various and sundry knowledge memes that already were created by the individual. So like biological evolution, an evolutionary view of adaptive cultural development depends on selection for the achievement of fit, and not transmission or instruction from world to mind by way of the senses of the type that Bacon and other empirical positivists believed possible.

But what about the propagation of knowledge to other individuals? Do not transmission and instruction play a role here comparable to the transmission of genetic information from parent to offspring? A little reflection suggests that the answer is no. The only way that John could possibly obtain knowledge from Mary is through his senses. Mary cannot transmit her genes to John, nor can she give him her brain or parts of it, or replicate the patterns of its structure in John's brain. Like the rest of the physical world, Mary is simply part of John's environment, knowable to him only through his senses. This does not mean that John cannot learn from Mary and her experiences. But as we saw in chapter 7, learning appears to be no more possible through instruction than is the Lamarckian inheritance of acquired characteristics. Accordingly, we will see in the next two chapters how current theories of language and education also reject the notion of the instructionist transmission of knowledge from one individual to another (as from teacher to student), and instead view linguistic communication and education as processes dependent on cumulative blind variation and selection.

[1]Popper (1979, p. 261).

[2]Kuhn (1970b, pp. 172-173).

[3]Darwin recognized that natural selection would require a very long time for complex forms of life and new

species to evolve. For this reason, he was troubled by Lord Kelvin's calculation (based on the temperature of the interior of the earth, the slowing of the earth's rotation by the action of tides, and the rate of decrease of the sun's heat) that the earth could not be more than 10 to 15 million years old, much too short to allow evolution to produce the diverse and complex forms of life existing on the earth. However, both radioactivity, which plays a major role in maintaining the earth's high interior temperatures, and nuclear fusion, which is the source of the sun's energy, were unknown phenomena in Kelvin's time. The earth is now considered to be about 4.5 billion (4500 million) years old, which is generally considered sufficient time for evolution to have brought forth the biosphere's current and past inhabitants. For an account of the conflict between Darwin and Kelvin concerning the age of the earth, see Burchfield (1975).

[4]Much of the information in this section is taken from Reader (1988, chapter 3). This book provides fascinating case studies of 12 different cultural groups and describes the ways in which their behaviors and beliefs are adapted to their environments. These include the Pacific islanders of Yap, slash and burn farmers of New Guinea, alpine pastoralists in the Swiss Alps, potato growers in the Andes, hunter-gatherers of the Kalahari Desert, and city dwellers of Cleveland, among others.

[5]The association of rice with fertility is not unknown in Western cultures, as revealed in the practice of throwing rice at newly married couples.

[6]Reader (1988, pp. 71-72).

[7]Reader (1988, p. 68).

[8]Reader (1988, p. 68).

[9]See Boyd & Richerson's (1985) concept of conformant transmission.

[10]Srinivas (1952; quoted in Harris, 1966, p. 51).

[11]See Badcock (1991, pp. 66-68).

[12]Trivers (1971).

[13]Axelrod (1984).

[14]Campbell (1991, p. 107).

[15]Campbell (1991, p. 98).

[16]Campbell (1991, p. 99).

[17]Campbell (1991, p. 99).

[18]At least from a short- or medium-term economic perspective.

[19]The sea otter places a flat rock on its chest and pounds clams and mussels against the rock to open them. Chimpanzees use long sticks to "fish" for termites. Two species of Darwin's finches on the Galápagos Islands trim cactus spines or leafstalks with their beaks and use these to extract grubs from the bark of dead tree branches (Weiner, 1994, p. 17)

[20]See Basalla (1988, pp. 15-16).

[21]Basalla (1988).

[22]Basalla (1988, p. 45).

[23]Basalla (1988, p. 136).

[24]Basalla (1988, p. 137).

[25]Mokyr (1990).

[26]Mokyr (1990, p. 275).

[27]Mokyr (1990, p. 276).

[28]Vincenti (1990).

[29]See also Bradshaw (1993a, 1993b).

[30]Vincenti (1990, p. 247).

[31]Vincenti (1990, pp. 247-248).

[32]Petroski (1985, p. 45; emphasis added).

[33]A distinction between experimental and analytical forms of vicarious trials has its merits. We will see, however, in chapter 13 how the increasing use of computer simulations in science and engineering has blurred this distinction.

[34]In addition to wind tunnel tests, the Wright brothers made use of kites to test wing shapes, miniature propellers to find ways of providing maximum thrust, and gliders to test means of flight control (see Bradshaw, 1993a, 1993b).

[35]Vincenti (1990, p. 250).

[36]It could similarly be argued that Einstein's formulation of relativity theory owed relatively little to technology, since Einstein relied primarily on his knowledge of physics, mathematics, and his own thought experiments to arrive at his theory.

[37]Bacon's method is still very much with us today, particularly in the social and behavioral sciences, where attempts are made to tease apart variables to determine which one is the actual cause of a certain phenomenon (e.g., is it the home environment or school environment that is responsible for success in school?).

[38]Bacon (quoted in Hesse, 1964, p. 144).

[39]It is not the case, as some critics have concluded, that Popper was a "naive falsificationist" who believed that a single disconfirmation of a theory entails its rejection. Instead, refutations of a theory may require many repeated disconfirming studies since in any one experiment equipment or methodological problems can lead to

erroneous disconfirming results.

[40]Popper (1979, p. 261).

[41]See Popper (1964).

[42]Although Popper puts forth important philosophical and logical arguments for a selectionist theory of science, he does not provide a picture of how scientists go about their day-to-day business interacting--both cooperating and competing--with other scientists. American biologist and philosopher David Hull spent many years investigating how scientists and scientific communities work, and he shares his findings in an interesting book (1988b).

[43]See Schilpp (1974) for a collection of 33 critiques of Popper's philosophy, followed by Popper's replies.

[44]Contemporary philosophers rejecting providential (foundational) and instructionist (empiricist, inductive) views of science include Campbell (1990), Feyerabend (1975), Giere (1988), Hanson (1958), Hull (1988a, 1988b), Kuhn (1970a, 1970b, 1991), Laudan (1984), Polanyi (1958), Quine (1960), Root-Bernstein (1989), Toul-min (1972), and van Fraassen (1980). Among these, Campbell, Giere, Hull, Kuhn, Root-Bernstein, and Toulmin make explicit use of an evolutionary or selectionist perspective to understand the development of science.

[45]See Hull (1988a, pp. 28ff.)

[46]Dawkins (1989, p. 192) coined the term *meme* (rhymes with *cream*) in 1976 and it has enjoyed growing popularity ever since. It is meant to represent a unit of imitation and is a shortened form of the Greek word *mimeme*, which also resembles memory and the French word *même* ("same").

[47]Dawkins (1989, p. 192).

[48]For example, Boyd & Richerson (1985) and Cavalli-Sforza & Feldman (1981). Indeed, the title of the latters' book is *Cultural Transmission and Evolution*.

[49]However, even this apparent transmission of genetic information involves selection mechanisms. The DNA molecule makes copies of itself by splitting lengthwise along its double helix. Each strand then selects complementary nucleotide bases from the soup of various molecules present in the cell's nucleus. It is through this process of blind molecular variation in the form of random molecular shuffling and selective retention that each single strand becomes another double-stranded DNA molecule that is almost always identical to the original parent molecule. The few errors that do arise constitute an important source of genetic variation on which natural selection can operate (see Li & Graur, 1991).